# Exploring the Potential of Educational Robots in Enhancing Mathematics Education for Students with Dyslexia: Towards Inclusive Multimodal Interfaces


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**Abstract.** Dyslexia is a learning difficulty characterised by challenges in information processing, particularly in phonological skills, working memory, and rapid naming, which can impact students' engagement with mathematical concepts like counting, spatial awareness, and basic operations. This paper highlights the potential use of educational robots (ER) to enhance mathematics education for students with dyslexia (SwD) through inclusive, multimodal interfaces. The authors adopted a human-centred design (HCD) approach to develop a low-cost, pedagogically informed educational robot aligned with the Irish mathematics curriculum to support SwD in primary schools. The HCD process involved collaboration with 27 first-class students (male, aged 6–7), three primary school teachers, and an expert in inclusive pedagogy and special educational needs, whose contributions directly informed the design of the accessible and engaging prototype robot. Additional participants will be involved in later stages of the HCD process. The prototype robot's design also incorporates universal design for learning (UDL) principles, offering multiple means of engagement, representation, and expression to foster inclusive mathematics education. The prototype robot was presented at a primary school in Dublin, Ireland, receiving positive feedback from students and teachers for enhancing engagement, accessibility, and understanding of mathematics. This feedback highlights the potential of ER to transform traditional mathematics education, providing new opportunities for inclusive learning.



**Keywords:** Educational robots, Dyslexia, Mathematics, Multimodal interface.


## 1 Introduction and Background

Students with dyslexia (SwD) commonly struggle with reading, writing, spelling, and phonemic awareness [1]. These difficulties can extend beyond literacy, leading to academic and occupational challenges, as well as emotional consequences such as low self-esteem and anxiety [2]. SwD often experience issues in executive function, working memory, and attention, which further complicate their learning processes [3]. These challenges can impact mathematics education, as dyslexia-related numeracy issues, such as digit reversal, symbol confusion, problem-solving difficulties, slow calculations, and spatial perception problems, contribute to a considerable gap in learning outcomes compared to their peers [4, 5]. Addressing these challenges is crucial to fostering an inclusive educational environment where all students have the opportunity to succeed. It is estimated that approximately 25% of individuals experience difficulties in mathematics, often linked to dyslexia or negative learning experiences, with around 60% of those with dyslexia facing specific challenges in mathematics [6]. While dyslexia significantly affects mathematics learning, it is not always associated with severe numeracy difficulties. However, the combination of literacy and mathematical challenges highlights the need for targeted interventions to support SwD in developing mathematical competence.

Traditional teaching methods often do not fully accommodate the diverse and unique learning needs of SwD, leading to frustration and disengagement. In contrast, educational robots (ER) present a promising approach to fostering an inclusive classroom environment. ER can be used not only for teaching robotics but also as interactive educational tools to reinforce mathematical concepts. By engaging in hands-on, multi-sensory activities, SwD can leverage their visual and kinaesthetic strengths, complementing traditional text-based methods [7, 8]. Mathematics language and its abstract presentation can be a significant barrier to understanding and problem-solving, especially for SwD, who may also struggle with sequencing and working memory. Developing ER can help minimise these challenges by translating mathematical concepts into interactive, visual, and less text-dependent formats. Research has demonstrated the potential of ER to improve mathematical problem-solving skills and conceptual understanding among students [7, 9]. ER offer interactive experiences that help SwD stay engaged and provide ample time for task completion [10, 11], which is essential for their learning process.

## 2 Robot Design

In September 2023, Ireland introduced a new primary mathematics curriculum, accompanied by a toolkit that includes key concepts and a "progression continua" to track student development and tailor instruction. The prototype robot developed for this study is designed to support this curriculum, incorporating the continua framework to help students, especially those with dyslexia, address specific learning challenges and enhance their mathematical skills through engaging interactive activities.

The prototype robot was developed using a human-centred design (HCD) approach, combining user-centred design (UCD) and co-design principles. UCD focuses on understanding the needs and preferences of the students to design a user-friendly and effective educational tool, while co-design actively involves teachers and students in the design process to ensure that the robot is tailored to their needs. The co-design process also integrated insights and recommendations from an expert in inclusive pedagogy and special educational needs, ensuring the robot is accessible and beneficial for all students, including those with learning challenges such as dyslexia.

The prototype robot design applies the universal design for learning (UDL) principles to support primary mathematics education for SwD. These principles include multiple means of engagement, representation, and action and expression. Implementing UDL principles supports the development of inclusive learning environments that empower students to succeed academically and beyond, with the support of assistive technologies such as ER [12]. These UDL principles can be tailored to support SwD, addressing their unique reading, writing, and information-processing challenges [13, 14] and take a broader approach by designing the learning environment upfront to accommodate diverse learning needs.

Promoting ownership among students in co-design processes enhances their engagement and deepens their sense of responsibility toward the outcomes, particularly in ER development. When students actively participate in shaping the design, they are more likely to feel invested in the developed robot's functionality, relevance, and success. Encouraging reflection during the design process helps foster students' critical thinking and supports their sense of ownership in co-design activities [15].

The HCD process led to the selection of the humanoid robot design, which includes a torso, head, and arms. This design choice holds the potential to enhance the robot's ability to engage students through a familiar, intuitive form that fosters social interaction and hands-on learning [16]. The prototype robot integrates a Raspberry Pi microcontroller and features interactive components, including touchscreen displays (x2), LEDs (x10), speakers (x2), microphone (x1), slide potentiometer (x1), push buttons (x9), and ‘8x8 LED matrix’ displays (x3). Current functions include teaching core mathematical concepts such as counting, addition, subtraction, money recognition, and spatial awareness. The prototype robot uses artificial intelligence (AI) and computer vision for handwriting recognition to improve its functions (e.g. addition/subtraction) and integrates text-to-speech (TTS) and speech-to-text (STT) for audio-visual interaction, enabling multimodal learning experiences.

The prototype robot's design promotes inclusive multimodal interfaces, supporting diverse learning needs through visual, auditory, and tactile engagement. Figure 1 below shows the main screen with the four functions the prototype robot is currently programmed to perform. The student can select a function either by touching the corresponding icon or by using voice commands. Each function is associated with a letter-based voice command, as follows:

- 'A' for addition and subtraction
- 'L' for locations (spatial awareness)
- 'C' for counting
- 'M' for money recognition

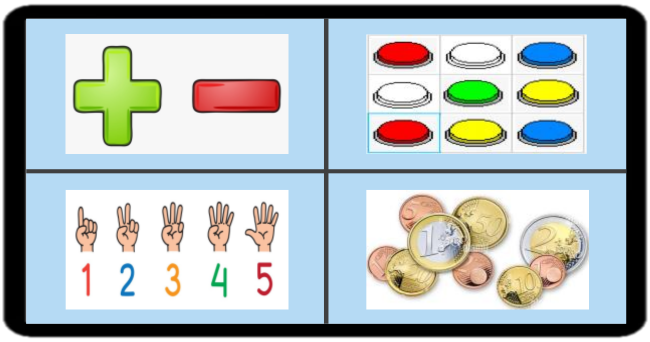


**Fig. 1.** The prototype robot's main screen displays four functions (top left: addition & subtraction, top right: locations, bottom left: counting, and bottom right: money recognition).

## 3 Methods

As part of the ongoing HCD process, the prototype robot was introduced, and its functions were demonstrated to 27 first-class students (male, aged 6–7), three primary school teachers, and an expert in inclusive pedagogy and special educational needs. The goal was to assess the prototype robot's effect on student engagement and its influence on interactive learning. The HCD process involved co-design sessions, which were recorded to capture detailed insights into participants' responses and their interactions with the prototype robot.

Semi-structured interviews were conducted with the teachers and the inclusive pedagogy and special educational needs expert, focusing on the prototype robot's alignment with the new Irish primary mathematics curriculum, educational value, usability, and potential influence on teaching practices. Meanwhile, the students provided feedback through surveys, which were designed to gather insights on their experiences with the prototype robot's design, ease of use, and functions. The data from semi-structured interviews and surveys were analysed qualitatively, with the responses transcribed and coded to identify key themes and patterns. This process seeks to refine the prototype robot's features to enhance its functionality and user experience.

The participating students reflected a wide range of mathematical abilities, from lower to higher performers. Selection was guided by their teachers' recommendations to ensure a representative mix of skill levels to facilitate the evaluation of how well the prototype robot aligns with the mathematics curriculum and supports diverse learner needs within the classroom setting. Recruiting students formally diagnosed with dyslexia at a young age is often challenging. In Ireland, children must be at least six years old and have received a minimum of 18 months of formal education before they are eligible for a dyslexia assessment [17]. However, including students as early as possible, particularly those showing potential early signs of dyslexia, is crucial for timely intervention.

The next phase of the ongoing HCD process will involve a more diverse and inclusive group of students. This includes both male and female students, either diagnosed with or exhibiting early signs of dyslexia. The HCD process will also expand across a wider age range, involving students from third to sixth class (ages 8–12). This expansion aims to refine the prototype robot's design to improve its accessibility and effectiveness, ensuring it can support inclusive mathematics learning experiences for all learners.

## 4 Results & Discussion

The robot prototype was tested in a primary school in Dublin, Ireland. Feedback from HCD participants indicated that the robot positively impacted student engagement, accessibility, and understanding of basic mathematical concepts during its initial trial. These results highlight the ER potential to address mathematics learning challenges. However, additional co-design sessions and testing are required to validate these findings. The robot's multimodal interface and alignment with universal design for learning (UDL) principles contributed to the positive outcomes. By incorporating UDL principles, ER can provide flexible and inclusive learning experiences, making mathematics more accessible. The involvement of diverse educational experts and the iterative design process within the HCD were key to creating an educational tool that resonates with students and teachers.

## 5 Conclusion

The learning needs of SwD deserve to be recognised, investigated and addressed. This paper highlights the potential of ER to transform mathematics education for all students, including those with dyslexia. Affordable, low-cost robots can play an essential role in education by providing interactive learning experiences. This study demonstrates that a structured and creative use of existing technology and resources when pedagogically aligned and engaging, can enhance mathematics learning. Future work will focus on refining the robot design through the HCD process and expanding its functionalities. Further testing with students with or showing signs of dyslexia will help refine its capabilities, reinforcing its potential to create more inclusive and accessible educational environment. This study contributes to the growing field of assistive technology, suggesting that ER can be valuable tools for facilitating accessible learning opportunities.

**Acknowledgement.** This work was conducted with the financial support of the Research Ireland Centre for Research Training in Digitally-Enhanced Reality (d-real) under Grant No. 18/CRT/6224. 

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